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Article (Published Version)

Mahmood, Asif, Khan, Sagheer, Hussain, Sajjad and Zeeshan, Muhammad (2021) Performance analysis of multi-user downlink PD-NOMA under sui fading channel models. IEEE Access, 9. pp. 52851-52859. ISSN 2169-3536

IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received March 15, 2021, accepted March 28, 2021, date of publication March 31, 2021, date of current version April 12, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3070147

Performance Analysis of Multi-User Downlink PD-NOMA Under SUI Fading Channel Models

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ABSTRACT Power Domain Non Orthogonal Multiple Access (PD-NOMA) is a multiple access technique that offers spectral efficiency, low latency and user fairness in 5G networks. This paper evaluates the performance of multi-user downlink PD-NOMA in suburban environments under SUI fading channels. Baseband modulated user signals with phase shifts are allocated power levels in accordance with users distance before the superposition coding is performed at the base station. A multi-level successive interference cancellation (SIC) is performed at the receivers. Bit error rate (BER) performance against signal-to-noise ratio (SNR) for up to four users per cluster is compared for all the SUI models corresponding to different suburban terrains with varying vegetation densities. An upper limit on number of users per cluster that are supported at a benchmark BER and SNR values is also evaluated.

INDEX TERMS Power domain non orthogonal multiple access (PD-NOMA), Stanford University Interim (SUI) models, successive interference cancellation (SIC).

I. INTRODUCTION

The development of 5th Generation (5G) communication systems is envisioned to match the increasing network capacity demands [1]. 4G communication systems utilized Orthogonal Multiple Access scheme (OMA) which works in Orthogonal Frequency Division Multiple Access (OFDMA) or Single Carrier-Frequency Division Multiple Access (SC-FDMA) [2], [3]. The OMA scheme however, fails to provide diverse range of Quality of Service (QoS) in large users network. This is due to the finite Degrees of Freedom (DoF) in such networks where users with rich channel conditions are served on priority basis whereas the users with poor channel conditions must wait for services [4]. In order to fulfil the demands of users in 5G networks, Non-Orthogonal Multiple Access (NOMA) schemes with superposition coding at the transmitter and Successive Interference Cancellation (SIC) [5], [6] at the receivers are being investigated. NOMA offers low latency, higher data rates, better connectivity and user fairness [7], [8]. Unlike the OMA schemes, the users in NOMA are served at the same time and frequency. The two types of NOMA, Power-Domain NOMA (PD-NOMA) and Code-Domain NOMA (CD-NOMA), have been presented in recent years [9], [10].

In PD-NOMA, user signals are assigned different power levels before the superposition coding is applied at the transmitter. The power levels are assigned on the basis of varying distances and channel gains for different users. In order to achieve user fairness in PD-NOMA, the signals of users farthest from transmitter are allocated highest power levels. While signals of users nearest to transmitter are allocated lowest power levels and so on. There are several studies in the literature that investigate PD-NOMA performance under different channel conditions. Performance analysis of two users downlink PD-NOMA under Rayleigh and Rician fading channels with different code rates and modulation schemes was carried out by Sadia *et al.* in [11]. The performance of Re-configurable Intelligent Surfaces (RISs) assisted downlink PD-NOMA was analyzed by Thirumavalavan *et al.* in [12]. The RISs are used to control the phase of multi-path signals in order to mitigate the signal degradation due to scattering and reflections. It was shown that the RIS assisted PD-NOMA outperforms conventional PD-NOMA in BER performance. Rabee *et al.* in [13] evaluated the BER performance of two user uplink PD-NOMA with SIC at the receive for both perfect and imperfect channel

The associate editor coordinating the review of this manuscript and approving it for publication was Debdeep Sarkar.

estimation. A higher BER was observed for QPSK and 16-QAM modulations as compared to BPSK. Yin *et al.* in [14] carried out the performance analysis of NOMA-2000 (CD-NOMA) and PD-NOMA techniques in uplink Rayleigh fading channels with and without user clustering. It was found that the PD-NOMA with user clustering outperforms the NOMA-2000 under different signal-to-noise ratios. Aldababsa *et al.* in [15] compared the performance of BPSK modulation in downlink NOMA over Rayleigh fading channels for perfect and imperfect SIC cases. It was shown that the diversity gain is proportional to the distance of users from base station. The users with higher distance had significantly better BER performance as compared to users with lower distance. Previous work [16] by the corresponding author investigated the performance of multi-user PD-NOMA under the New York University Simulator (NYUSIM) channel Model [17]. The performance analysis was carried out to determine appropriate power factors for different modulation schemes.

Radio channel is characterized by multi-path delay spread, fading characteristics, path loss (including shadowing), Doppler spread, and co-channel and adjacent channel interference. The SUI models address three types of terrains with varying vegetation densities in suburban areas, each consists of two channels with diverse delay spread, Doppler spread, Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) parameters [18]. Tiwana et al in [19] analyzed the BER performance of filter bank multi-carrier (FBMC) modulation for different scenarios under SUI channels. The impact of angle of arrival (AoA) and angular spread on the channel capacity of narrow and wideband MIMO channels under SUI-3, 4 and 5 models was investigated in [20]. Sulyman et al in [21] presented the modified path loss (PL) equations for SUI channel model at frequency bands of 28 and 38 GHz. Furthermore, the frequency correction factor and receiver height correction factor were presented at 60 GHz and 73 GHz bands. In the available literature such as presented in references [9], [11], [12] and [13] most authors evaluates the performance of PD-NOMA in different channel models for two users in general.

This paper presents the performance analysis of multi-user PD-NOMA under SUI channel models for suburban environments with modest to heavy vegetation densities. The performance of two, three and four users per cluster PD-NOMA is evaluated in terms of bit error rate versus signal to noise ratio for baseband BPSK modulation scheme over SUI fading channels. The maximum number of users per cluster that can support a threshold BER at a specified maximum SNR under different SUI models is determined. This paper thus aims to provide insights into performance of denser NOMA systems in realistic fading channels in suburban areas. BER curves are computed through simulations by implementing the system model as discussed in section II. Phase shift of $\pi/2$ among users signals during modulation stage is introduced to reduce inter-symbol interference (ISI). The standard values of channel parameters for SUI models are considered for performance evaluation. The users are considered stationary for best performance. The users at same height and distance from BS can be differentiated using spreading sequences as done in a previous work [22]. This case is, however not encountered in this study as only a single cluster case with maximum user separation (i.e. the distance between two consecutive users is at least twice the distance between BS and the nearest UE and so on) is presented as shown in Table 2, 3 and 4.

The rest of the paper is organized as follows. Section II describes the system model followed by an introduction of successive interference cancellation (SIC) technique and section III discusses SUI models and multi-user NOMA under SUI channels. Section IV provides the results comparisons and the paper is concluded in section V.

II. SYSTEM MODEL

A SISO downlink power domain NOMA is shown in Fig. 1 in which a base station (BS) is transmitting a composite signal towards N user equipment (UEs). Each user's signal is base-band modulated using Binary Phase Shift Keying (BPSK) and allocated a respective power factor based on its distance from BS. Superposition coding is performed at the BS to form a composite signal. The composite signal is passed through SUI channel in the presence of AWGN. Root raised cosine (RRC) filter is used at both the transmitter and receiver for pulse shaping to mitigate ISI. The received signal is decoded by each receiver using different levels of SIC. The block diagram of the system is shown in Fig. 2.

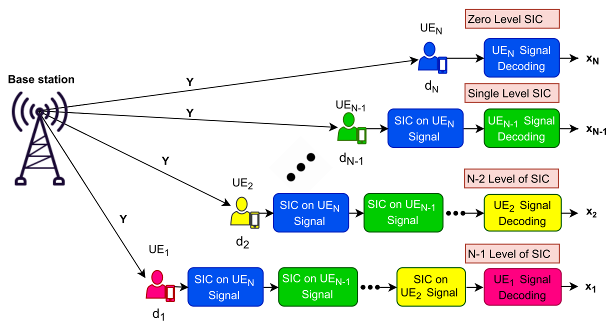


FIGURE 1. SISO downlink PD-NOMA model of N UE's (UE_1 is nearest and UE_N is farthest to the BS).

The users signals of a cluster are modulated and assigned with respective power factor such that the composite signal by the BS can be given as follows.

$$c_m(t) = \sum_{k=1}^{N} \sqrt{p_k} s_{m,k}(t) \tag{1}$$

where, $m = 1, 2, 3, \ldots M$ is the number of clusters; and $k = 1, 2, \ldots N$ is the number of users in a cluster; $s_{m,k}(t)$ is the message signal for k^{th} user of the m^{th} cluster; and p_k is the respective power factor assigned. In order to bring user fairness in PD-NOMA, lower power levels are allocated to UEs nearest to the BS and higher power levels are allocated

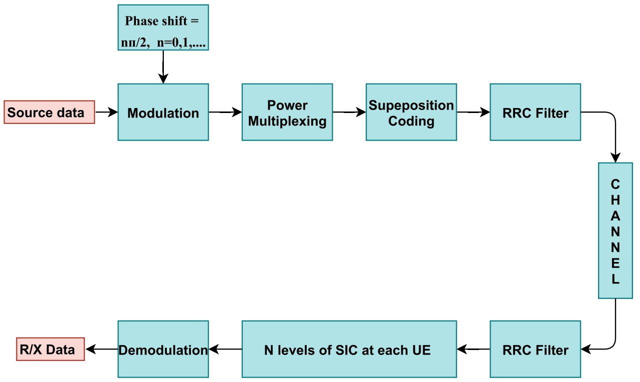


FIGURE 2. Block diagram for all the steps taken between Tx and Rx in the proposed PD-NOMA system.

to UEs farthest from the BS and so on. The power levels are assigned such that the sum of all power factors is unity. i.e.

$$\sum_{k=1}^{N} p_k = 1 \tag{2}$$

Please note that in order to overcome the large interference among multiple users within the cluster, this paper introduces phase shifts during modulation of users signals. A maximum phase shift of $\pi/2$ is introduced among users,

$$\text{Phase shift} = \pm n\pi/2 \qquad n = 0, 1, 2 \ldots\ldots \tag{3}$$

where $n = 0$ to $N - 1$ and N is the total number of users per cluster. e.g. in a four users per cluster, the signals for UE_1, UE_2, UE_3 and UE_4 have phase shifts of 0, $\pi/2$, π and $3\pi/2$ respectively. The allocation of power levels is based on the distance of each user as in [16] such that,

$$p_i{}' = \frac{d_i}{d_{max}} \qquad i = 1, 2 \ldots\ldots N \tag{4}$$

where p_i' is the absolute power factor, d_i is the distance of ith user from BS and $d_{max} = 200\ m$ (typical BS radius in 5G networks). The power factors are normalized between 0 and 1 as follows,

$$p_i = \frac{p_i'}{\sum_{i=1}^{N} p_i'} \qquad i = 1, 2 \ldots\ldots N \tag{5}$$

The composite signal of each cluster $c_m(t)$ is then passed through RRC filter such that,

$$x_m(t) = \sum_j c_m(j) g(t - kT) \tag{6}$$

where $x_m(t)$ is the transmitted signal for a cluster and $g(t)$ is the response of RRC filter. The signals of each cluster are superimposed such that,

$$x(t) = \sum_{m=1}^{M} x_m(t) \tag{7}$$

$x(t)$ is the composite signal that passes through SUI channel model. The received signal at each UE that undergoes large-scale fading is given by,

$$y_k(t) = \alpha_k . x(t) + n_k(t) \qquad k = 1, 2, 3 \ldots \tag{8}$$

where, α_k is the path gain and n_k is the AWGN for k^{th} user. Each UE receives the composite signal which is again passed through RRC filter for pulse shaping to reduce ISI. The signal is then decoded by performing different levels of SIC at each receiver as shown in Fig. 3 and is given by,

$$\hat{x_k}(t) = y_k(t) - \sum_l x_l(t) \tag{9}$$

where $l = 0$ for farthest UE to $l = N - 1$ for nearest UE respectively.

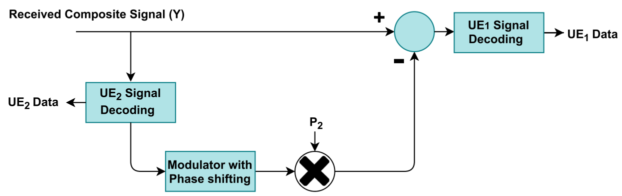


FIGURE 3. SIC at the Rx of UE_1 in two users per cluster PD-NOMA system.

A. MULTI-LEVEL SIC TECHNIQUE

SIC is a key feature of NOMA to cancel the effect of interfering signals from other users. Composite signal having all the users signal is received at each receiver. In an N users cluster, the UE nearest to the BS performs N-1 levels of SIC, second nearest UE performs N-2 levels of SIC and so on. The farthest user directly decodes its signal from the composite signal without performing the SIC. In order to bring user-fairness, the total transmits power is distributed on the basis of user's distance and channel coefficients. The signals with highest power levels are decoded first, followed by others with low power levels in descending order. In a typical two users PD-NOMA system with UE_1 (Cell-center user) and UE_2 (Cell-edge user), SIC is performed by the nearest user UE_1 to cancel the effect of interference caused by UE_2's signal. UE_2's signal with higher power level is demodulated and decoded first at the receiver of UE_1. The signal is again modulated, multiplied with its own power factor and subtracted from the composite signal to decode UE_1 signal. This is shown below in Fig. 3

Similarly, in a four users per cluster PD-NOMA system each UE must decodes the signals having higher power levels as shown in Fig. 4. The farthest user, UE_4 in this case, directly decodes its signal from the composite signal. UE_3, the second farthest user performs SIC by first decoding UE_4 signal, modulating UE_4's signal, multiplying it with its power factor and subtracting it from the composite signal. Thus the composite signal is left with UE_3 signal as highest power signal and is decoded. In a similar way UE_2 receiver performs SIC on UE_4 and UE_3 data signals and UE_1 performs SIC on UE_4, UE_3 and UE_2 signals to retrieve its own signals respectively.

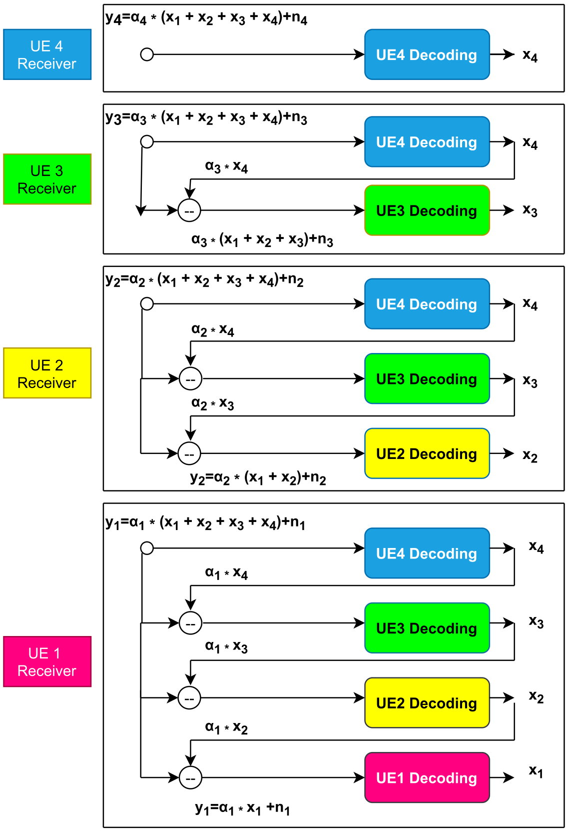


FIGURE 4. Block diagram of SIC in four users per cluster PD-NOMA system.

III. STANFORD UNIVERSITY INTERIM (SUI) CHANNEL MODELS

SUI channel models are based on Erceg's model [23] and are developed for suburban environments with modest to heavy vegetation density. Extension of an early work carried out by American Telephone & Telegraph Company ($AT\&T$) Wireless is the SUI propagation loss model and is proposed by Erceg *et al.* in [24]. Based on topography, the SUI models are further classified into A, B and C categories as follows.

- Category A, consists of SUI-5 and 6 models which corresponds hilly terrain with average to heavy tree densities, resulting in the maximum path loss (PL).
- Category B, consists of SUI-3 and 4 models and is used in hilly topographic climate with exceptional vegetation, or high vegetation but flat terrain environment, which results in moderate PL.
- Category C, consists of SUI-1 and 2 models and is used in flat terrain with small tree densities, which results in minimum PL.

The general PL equation is modified for SUI models above 2 GHz frequency bands as discussed in [21], [25] and [26] with frequency correction X_{fc} and receiver height correction X_{RX} factors, where the PL_{SUI} in dB are given as follows.

$$PL_{SUI}(d)[dB] = FSPL(f, 1m)[dB] + 10nlog_{10}(d/d_0) + X_{fc} + X_{RX} + X\sigma \quad (10)$$

where,

$$\begin{aligned} FSPL(1m)[dB] &= 20.log_{10}(\frac{4\pi f}{3 \times 10^8}) \\ &= 32.4[dB] + 20log_{10}(f_{GHz}) \quad (11) \\ n &= a - b.h_{TX}(m) + \frac{c}{h_{TX}(m)} \quad (12) \\ X_{fc} &= 6log_{10}(\frac{f_{MHz}}{2000}), f > 2GHz \quad (13) \\ X_{RX} &= -10.8log_{10}(\frac{h_{RX}(m)}{2}), \\ &\quad \text{for terrain types A and B} \quad (14) \\ X_{RX} &= -20.log_{10}(\frac{h_{RX}(m)}{2}), \\ &\quad \text{for terrain type C} \quad (15) \end{aligned}$$

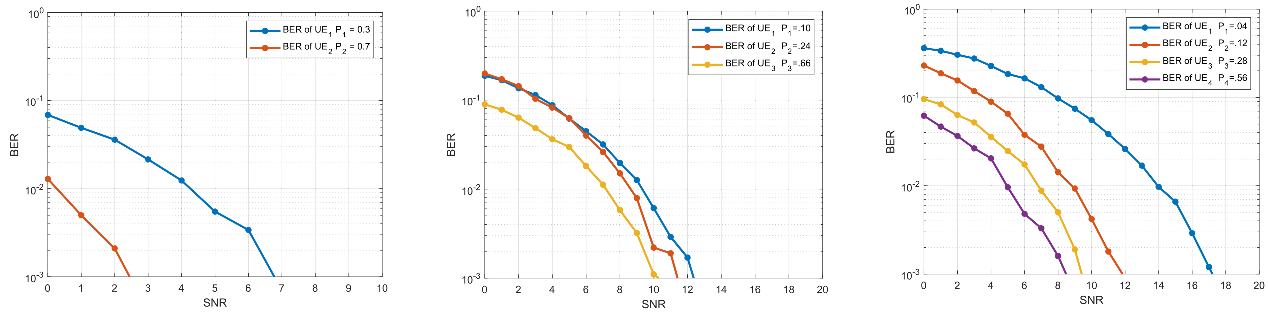
where f, f_{MHz} and f_{GHz} are carrier frequencies in Hz, MHz and GHz respectively; n is the path loss coefficient; FSPL is the free space path loss in dB at reference distance of 1m; X_{RX} and X_{fc} are the correction components for receiver heights and frequencies respectively; and X_σ is zero mean shadowing variable with standard deviation σ. The categories A, B and C as discussed above are characterized on the basis of Doppler spread, delay spread and LOS or NLOS (K-factor) conditions. The multi-user PD-NOMA model presented in this paper uses the standard values of these channel parameters for SUI models in terrain type A, B and C as listed in Table 1

TABLE 1. SUI models specification for terrain A, B and C.

Properties	SUI					
	1	2	3	4	5	6
Terrain Type	C	C	B	B	A	A
K-Factor	4	2	1	0	0	0
Path Delay Vector (s)	[0 0.4 0.9]	[0 0.4 1.1]	[0 0.4 0.9]	[0 1.5 4]	[0 4 10]	[0 14 20]
Path Gain Vector (dB)	[0 -15 -20]	[0 -12 -15]	[0 -5 -10]	[0 -4 -8]	[0 -5 -10]	[0 -10 -14]
Doppler Spread (Hz)	0.5	0.25	0.5	0.25	2.5	0.5

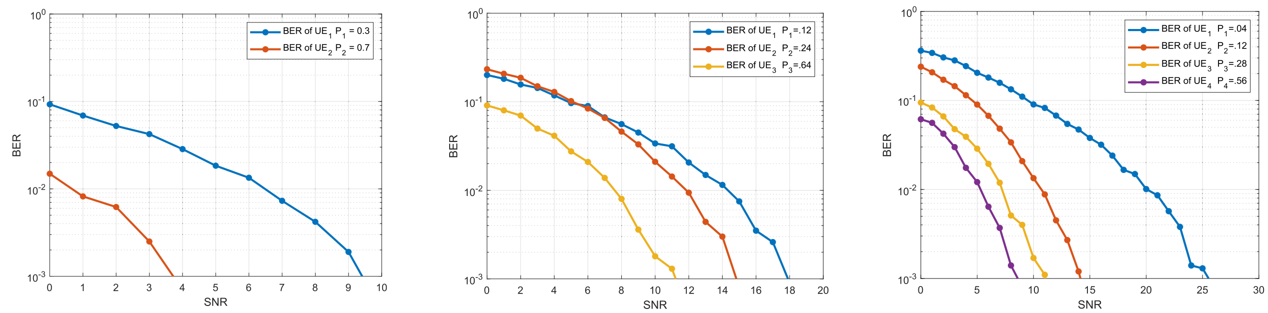
IV. SIMULATION RESULTS

The proposed multi-user PD-NOMA with two, three and four users per cluster under SUI fading channels SUI-1, SUI-2, SUI-3, SUI-4, SUI-5 and SUI-6 are simulated. User-clustering is carried out on the basis of (Best with poor model), where users are placed in a cluster with increasing order of distances from the BS. Best with poor model means the clusters having users of best and poor channel conditions. RRC filter used for pulse shaping at both the BS and UE, has Roll off factor of 0.25 and 0.5, span of 6 and samples per symbol is 4. Phase shifts of $\pi/2$ are introduced in users signals during the modulation. The performance is evaluated on the basis of average Bit Error Rate (BER) against Signal-to-Noise Ratio (SNR). The initial simulation results showed that 2 and 3 UEs per cluster in SUI-1 and SUI-2 models can achieve lowest BER (up to 10^{-9}) at lower values of SNR as expected. However the BER performance is further degraded with the increasing number of UEs per cluster and going from



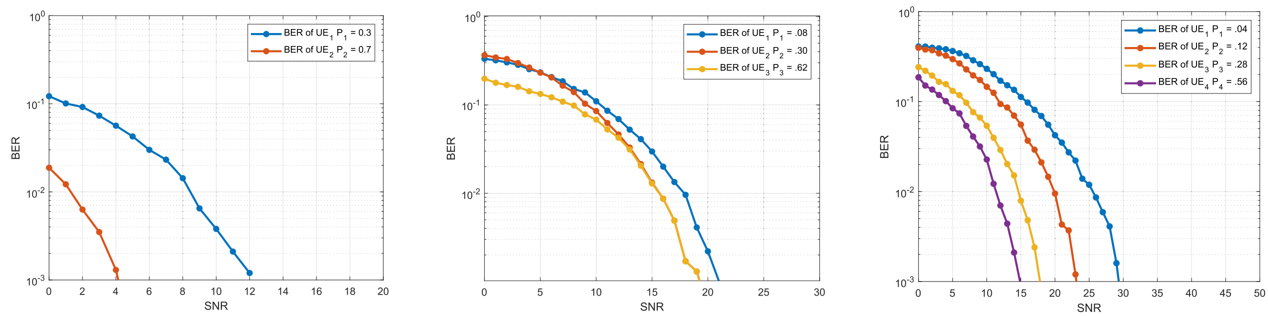
(a) 2 UE's SUI-1 model (b) 3 UE's SUI-1 model (c) 4 UE's SUI-1 model

FIGURE 5. **BER performance of 2, 3 and 4 UE's per cluster PD-NOMA system under SUI-1 channel model.**



(a) 2 UE's SUI-2 model (b) 3 UE's SUI-2 model (c) 4 UE's SUI-2 model

FIGURE 6. **BER performance of 2, 3 and 4 UE's per cluster PD-NOMA system under SUI-2 channel model.**



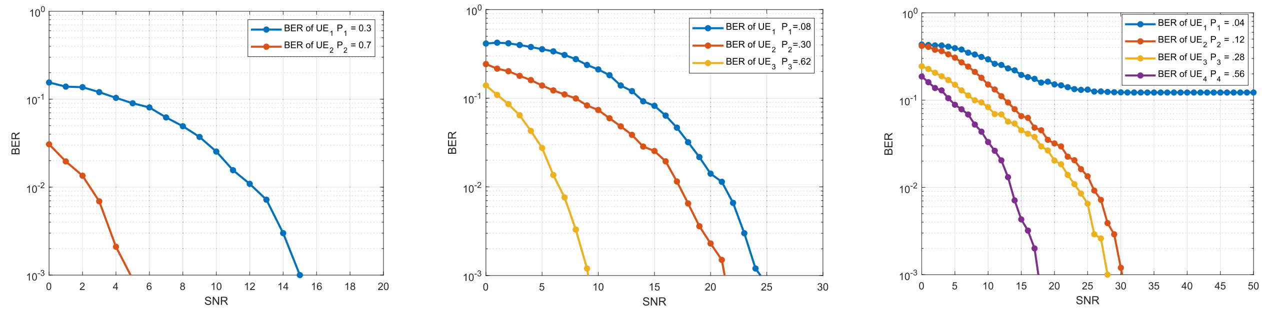
(a) 2 UE's SUI-3 model (b) 3 UE's SUI-3 model (c) 4 UE's SUI-3 model

FIGURE 7. **BER performance of 2, 3 and 4 UE's per cluster PD-NOMA system under SUI-3 channel model.**

SUI-2 to SUI-6 models. Keeping a threshold BER at 10^{-6} or 10^{-9} would require a very high value of SNR for 4 UEs per cluster in SUI-4, SUI-5 and SUI-6 models. Therefore, a fixed threshold BER of 10^{-3} is chosen for all the results. BER performance for different users per cluster in six SUI models investigated are shown in Figures 5 to 10. Each figure has three sub-figures that shows the performance for two, three and four users per cluster respectively for the given SUI model. Therefore the performance of multi-user PD-NOMA under SUI fading channels can be compared in two ways.

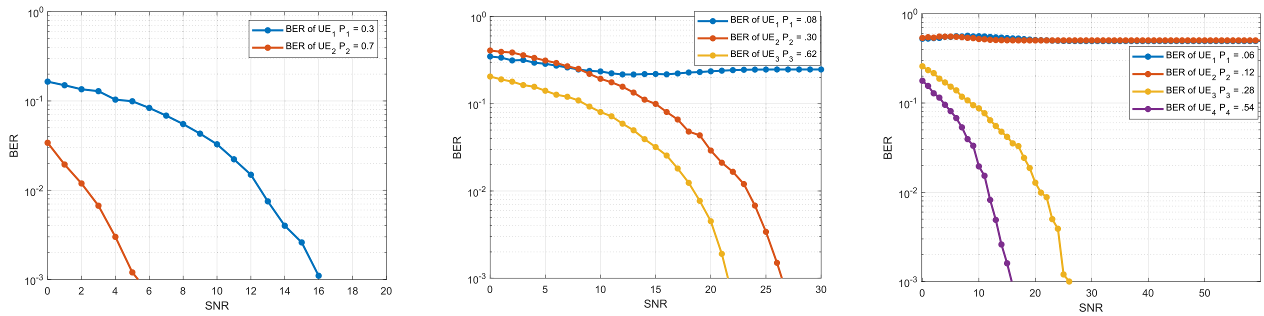
- BER performance comparison for different users per cluster in same SUI channel. This is evident by comparing horizontally between sub-figures within a figure.
- BER performance comparison for same number of users per cluster for different SUI channels. This is evident by comparing vertically between same sub-figures (a, b or c) of all the figures.

In particular, Fig. 5 shows the performance analysis for two, three and four users per cluster in SUI-1 channel in sub-figures (a), (b) and (c) respectively. It can be seen in Fig. 5(a) for two users per cluster that the nearest user with smaller power factor and single SIC level exhibits poor BER performance as compared to the farthest user in SUI-1 channel. Increasing the number of users per cluster in SUI-1 channel shows the similar trend in performance as can be seen in 5(b) and 5(c). For three users per cluster in Fig. 5(b),



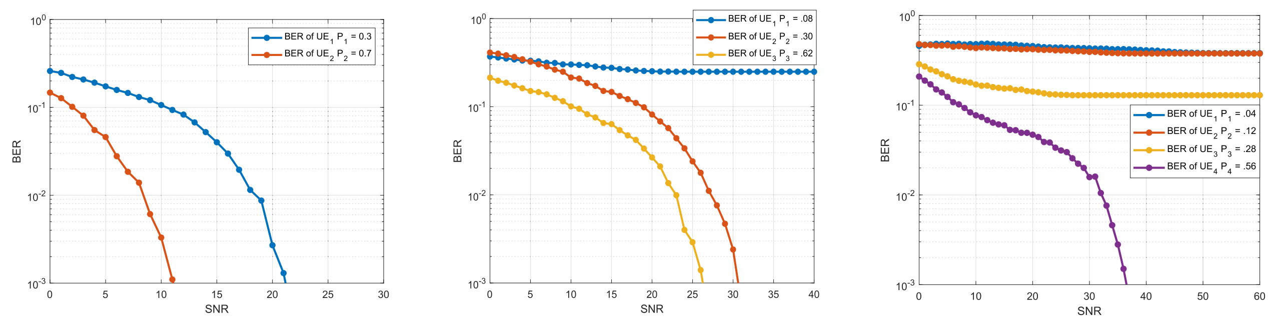
(a) 2 UE's SUI-4 model (b) 3 UE's SUI-4 model (c) 4 UE's SUI-4 model

FIGURE 8. **BER performance of 2, 3 and 4 UE's per cluster PD-NOMA system under SUI-4 channel model.**



(a) 2 UE's SUI-5 model (b) 3 UE's SUI-5 model (c) 4 UE's SUI-5 model

FIGURE 9. **BER performance of 2, 3 and 4 UE's per cluster PD-NOMA system under SUI-5 channel model.**



(a) 2 UE's SUI-6 model (b) 3 UE's SUI-6 model (c) 4 UE's SUI-6 model

FIGURE 10. **BER performance of 2, 3 and 4 UE's per cluster PD-NOMA system under SUI-6 channel model.**

the nearest user with lowest power factor and two levels of SIC achieves threshold BER of 10^{-3} at SNR of 12.3 dB; the second nearest user with single level of SIC achieves threshold BER of 10^{-3} at SNR of 11.4 dB; and the farthest user achieves threshold BER of 10^{-3} at SNR of 10 dB respectively in SUI-1 channel. Likewise, for four users per cluster in Fig. 5(c), the nearest user with lowest power factor and three levels of SIC achieves threshold BER of 10^{-3} at SNR of 17 dB; the second nearest user with two level of SIC achieves threshold BER of 10^{-3} at SNR of 11.9 dB; third user with single level of SIC achieves threshold BER of 10^{-3} at SNR of 9.5 dB; and the farthest user achieves threshold BER of 10^{-3} at SNR of 8.5 dB respectively in SUI-1 channel. This shows that the BER performance improves directly with increasing distance separation and allocated power factor for a user in the cluster.

A similar trend is observed for SUI-2, SUI-3, SUI-4, SUI-5 and SUI-6 models in Figures 6, 7, 8, 9 and 10 respectively. In order to compare the performance of same number of users per cluster in different SUI models, consider two users per cluster case for SUI-1 and SUI-2 as shown in 5(a) and 6(a) respectively. For the same threshold BER of 10^{-3}, the nearest user in SUI-1 achieves SNR of 6.8 dB as compared to 9.4 dB in SUI-2; the farthest user in SUI-1 achieves SNR of 2.4 dB as compared to 3.8 dB in SUI-2. Thus BER performance for both the users in SUI-2 degrade as compared to SUI-1

TABLE 2. Summary of the performance analysis of 2 UE's per cluster PD-NOMA under SUI fading channels.

Parameters	SUI-1		SUI-2		SUI-3		SUI-4		SUI-5		SUI-6	
	UE_1	UE_2	UE_1	UE_2	UE_1	UE_2	UE_1	UE_2	UE_1	UE_2	UE_1	UE_2
Distance in meter from BS	45	105	45	105	45	105	45	105	45	105	45	105
Power Factors P.F	0.3	0.7	0.3	0.7	0.3	0.7	0.3	0.7	0.3	0.7	0.3	0.7
SNR (dB) achieved	6.8	2.4	9.4	3.8	12	4	15	4.8	16	5.2	21	11
BER Threshold	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}

TABLE 3. Summary of the performance analysis of 3 UE's per cluster PD-NOMA under SUI fading channels.

Parameters	SUI-1			SUI-2			SUI-3			SUI-4			SUI-5			SUI-6		
	UE_1	UE_2	UE_3	UE_1	UE_2	UE_3	UE_1	UE_2	UE_3	UE_1	UE_2	UE_3	UE_1	UE_2	UE_3	UE_1	UE_2	UE_3
Distance in meter from BS	30	72	198	36	72	192	27	90	183	24	90	186	24	90	186	24	90	186
Power Factors P.F	.10	.24	.66	.12	.24	.64	.08	.30	.62	.08	.30	.62	.08	.30	.62	.08	.30	.62
SNR (dB) achieved	12.3	11.4	10	18	14.8	11.2	21	19	19	24.5	21.5	9	–	26.5	21.5	–	30.5	26
BER Threshold	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}

TABLE 4. Summary of the performance analysis of 4 UE's per cluster PD-NOMA under SUI fading channels.

Parameters	SUI-1				SUI-2				SUI-3				SUI-4				SUI-5				SUI-6			
	UE_1	UE_2	UE_3	UE_4	UE_1	UE_2	UE_3	UE_4	UE_1	UE_2	UE_3	UE_4	UE_1	UE_2	UE_3	UE_4	UE_1	UE_2	UE_3	UE_4	UE_1	UE_2	UE_3	UE_4
Distance in meter from BS	12	36	84	168	12	36	84	168	12	36	84	168	12	36	84	168	12	36	84	168	12	36	84	168
Power Factors P.F	.04	.12	.28	.56	.04	.12	.28	.56	.04	.12	.28	.56	.04	.12	.28	.56	.04	.12	.28	.56	.04	.12	.28	.56
SNR (dB) achieved	17	11.9	9.5	8.5	25.5	14	11	8.5	29.5	23	18	15	–	30	28	17.5	–	–	26	16	–	–	–	36
BER Threshold	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}

TABLE 5. Number of recommended UEs per cluster PD-NOMA in SUI channel models.

Category	Models	2 UEs cluster		3 UEs per cluster			4 UEs per cluster				N_{max}
		UE_1	UE_2	UE_1	UE_2	UE_3	UE_1	UE_2	UE_3	UE_4	
Category C	SUI-1	✓	✓	✓	✓	✓	✓	✓	✓	✓	4
	SUI-2	✓	✓	✓	✓	✓	✓	✓	✓	✓	4
Category B	SUI-3	✓	✓	✓	✓	✓	✓	✓	✓	✓	4
	SUI-4	✓	✓	✓	✓	✓	×	✓	✓	✓	3
Category A	SUI-5	✓	✓	×	✓	✓	×	×	✓	✓	2
	SUI-6	✓	✓	×	✓	✓	×	×	×	✓	2

for two users per cluster case. This is further evident from comparisons of BER performances of same number of users in different SUI models. The performance for same number of users per cluster decreases from SUI-1 to SUI-6 models due to the increasing tap delays and decreasing K factor that results in reduction of received power as we go from SUI-1 to SUI-6 channel respectively. The performance of two users per cluster, three users per cluster and four users per cluster PD-NOMA under SUI models are summarized in Table 2, 3 and 4 respectively.

It is also evident from Figures 8, 9 and 10 that the BER curves for some users in SUI-4, SUI-5 and SUI-6 models remain flat and do not follow the typical waterfall behaviour despite the increase in the SNR. In particular, UE_1 in four users per cluster SUI-4, three users per cluster SUI-5 and three users per cluster SUI-6 shows flat BER curve. Likewise, UE_1 and UE_2 in four users per cluster SUI-5; and UE_1, UE_2 and UE_3 in four users per cluster SUI-6 exhibit flat BER curves. This is also in line with the observed behaviour that the performance degrades with increasing number of users per cluster and changing the models from SUI-1 to SUI-6. Based on these results, the maximum number of users per cluster (N_{max}) that support a threshold BER of 10^{-3} at maximum SNR of 40dB can be identified as shown in Table 5. It can be seen that the SUI-1 and SUI-2 models corresponding to Category C for flat terrains with low tree densities can support up to four users per cluster for the specified BER and SNR values. The SUI-3 and SUI-4 models corresponding to Category B for hilly terrains or flat terrains with high tree densities can also support a maximum of four users per cluster. The SUI-5 and SUI-6 models corresponding to Category A for hilly terrains with average to heavy tree densities can support a maximum of two users per cluster.

V. CONCLUSION

This paper presents the performance analysis of multi-user PD-NOMA under SUI fading channels in suburban environments. Power levels for user signals are allocated on the basis of varying distance in best with poor model of user clustering. Maximum phase shifts are introduced to further improve the performance. The standard values of channel parameters are used to evaluate the BER performance for two, three and four users per cluster PD-NOMA for SUI-1, SUI-2, SUI-3, SUI-4, SUI-5 and SUI-6 models. Increasing the number of users per cluster degrades the BER performance in multi-user PD-NOMA under SUI fading channels. The performance for same number of users per cluster degrades from SUI-1 model to SUI-6 model due to increasing tap delays and decreasing K factor. Category A of SUI models for hilly suburban terrains with average to heavy tree densities support a maximum of two users per cluster for a threshold BER of 10^{-3} at maximum SNR of 40 dB. Categories B and C of SUI models corresponding to hilly terrains with low vegetation and flat terrains with tree densities respectively can support a maximum of four users per cluster for the same BER and SNR values.

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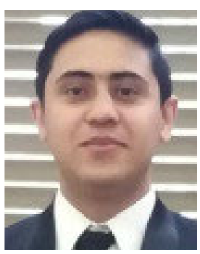

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